NETL's Research on Natural Gas Quality and Interchangeability

Presented to:
CEC Natural Gas Interchangeability Stakeholder Advisory Committee Meeting
October 29, 2007

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Outline

- **Motivation, scope, and history of DOE/NETL effort**
- **Executive overview of key results**
  - Gap analysis and database development
  - Pipeline mixing
  - Recip. engines
  - Gas turbines
  - Sensors
  - HC dewpoint studies
- **Lean premixed combustion (for gas turbines)**
  - Gas composition effects on emissions
- **Final report:**
  - http://www.ferc.gov/industries/lng/indus-act/issues/gas-qual.asp

What Is the Motivation For This Effort?

- **Future demand for natural gas will increase**
- **Future "pipeline" gas sources will vary**
  - Energy Information Agency projections
  - Annual Energy Outlook 2007

Figure 75. Natural gas production by source, 1990-2030 (trillion cubic feet)

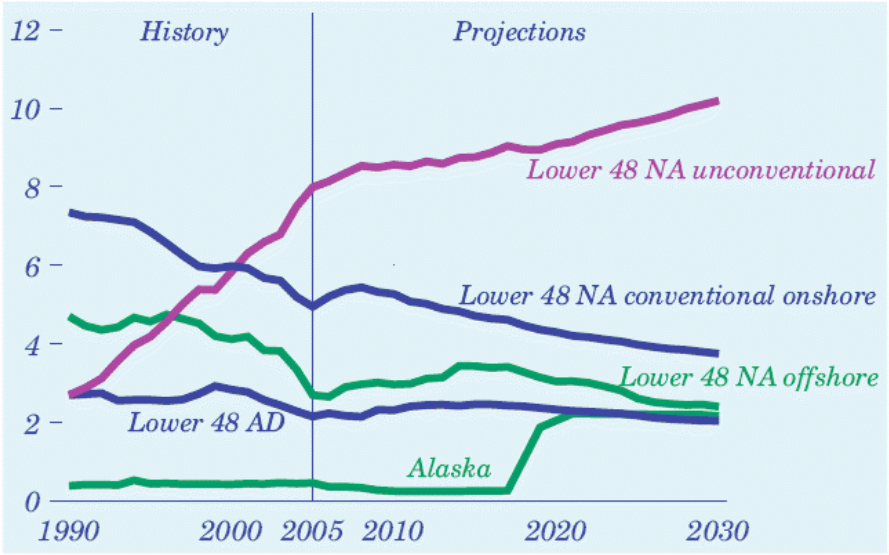
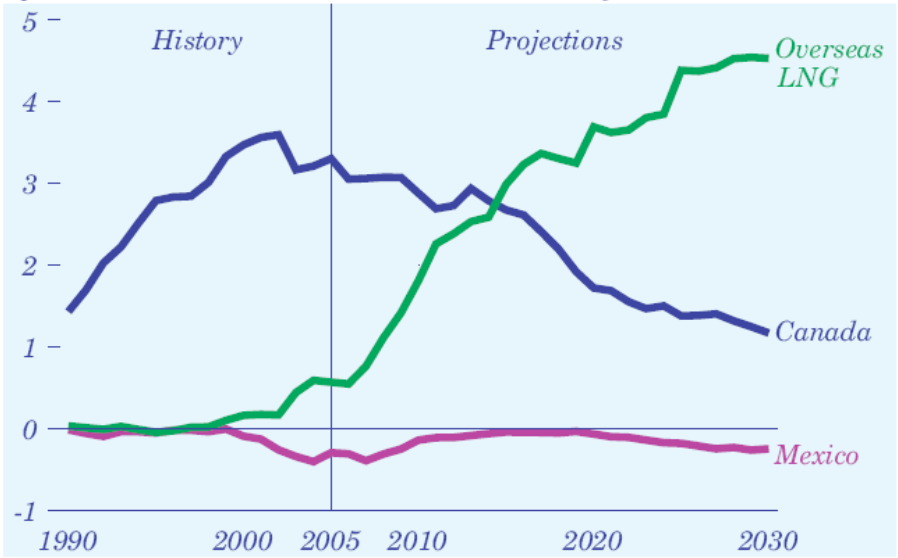


Figure 77. Net U.S. imports of natural gas by source, 1990-2030 (trillion cubic feet)



Reference: http://www.eia.doe.gov/oiaf/aeo/

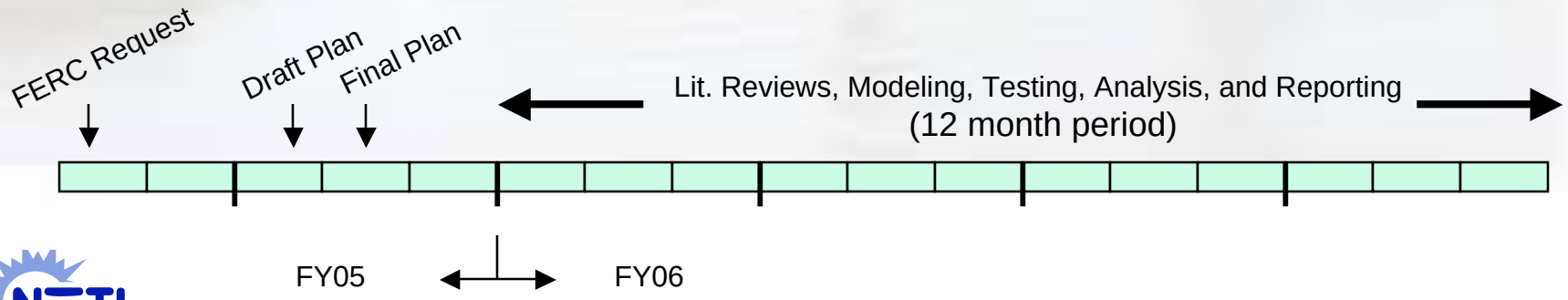
What Is the Scope Of Fuel Variations?

- **Different fuel sources lead to different fuel compositions**
  - Liquefied Natural Gas (LNG) Imports
    - Higher BTU value
    - Higher percentage of C2's and C3's
    - Lower level of inerts
  - Unconventional sources
    - Coal-bed methane
    - Tight sandstone formations
    - Gas shales
  - Low BTU fuels
    - Biomass
    - Syn-gas

Focus of This Effort

History/Chronology of Project
(1 of 2)

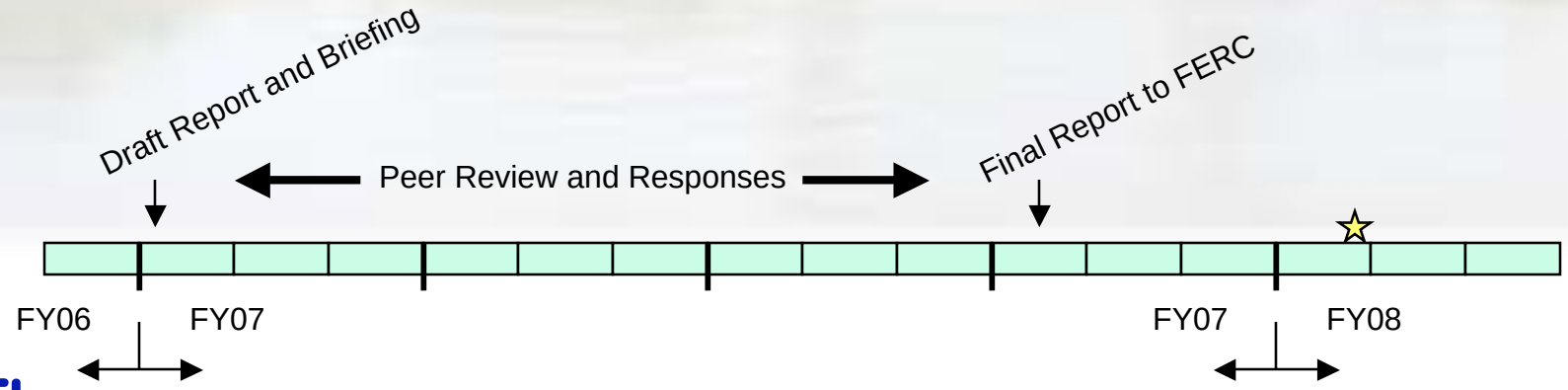
- May 2005 – Request from FERC Chairman Wood for DOE to conduct LNG Interchangeability research
- June 16, 2005 – Secretary response that FE would lead the research effort
- June 22, 2005 – NETL to work with FERC staff to develop a research plan
- July 25, 2005 – Draft "Path Forward" presented to HQ/FERC
- August 19 & December 14, 2005 – Finalized work plan with FERC to include additional concerns (i.e., dropout)



History/Chronology of Project
(2 of 2)

- October 5, 2006 – HQ/FERC briefing and draft report completed. Peer-review initiated.
- April 2007 – Peer-review comments received and organized
- July 2007 – Peer-review comments addressed and final report delivered to FERC

- Oct 23, 2007 – Final Report available on FERC web-site
  - –http://www.ferc.gov/industries/lng/indus-act/issues/gas-qual.asp



Overview of NETL Tasks

- **Gather information and develop database**
  - Public info. on gas composition and effects on equipment
- **Pipeline mixing**
  - Steady-state and transient mixing behavior
- **Reciprocating engines**
  - Literature review only
- **Stationary gas turbines**
  - Literature review, modeling, and experiments
- **Sensors for gas composition**
  - Review available technology and recent advances
- **HC dewpoint predictions**
  - Assess models predictions for C6+

Results - Database Development and "Gap Analysis"

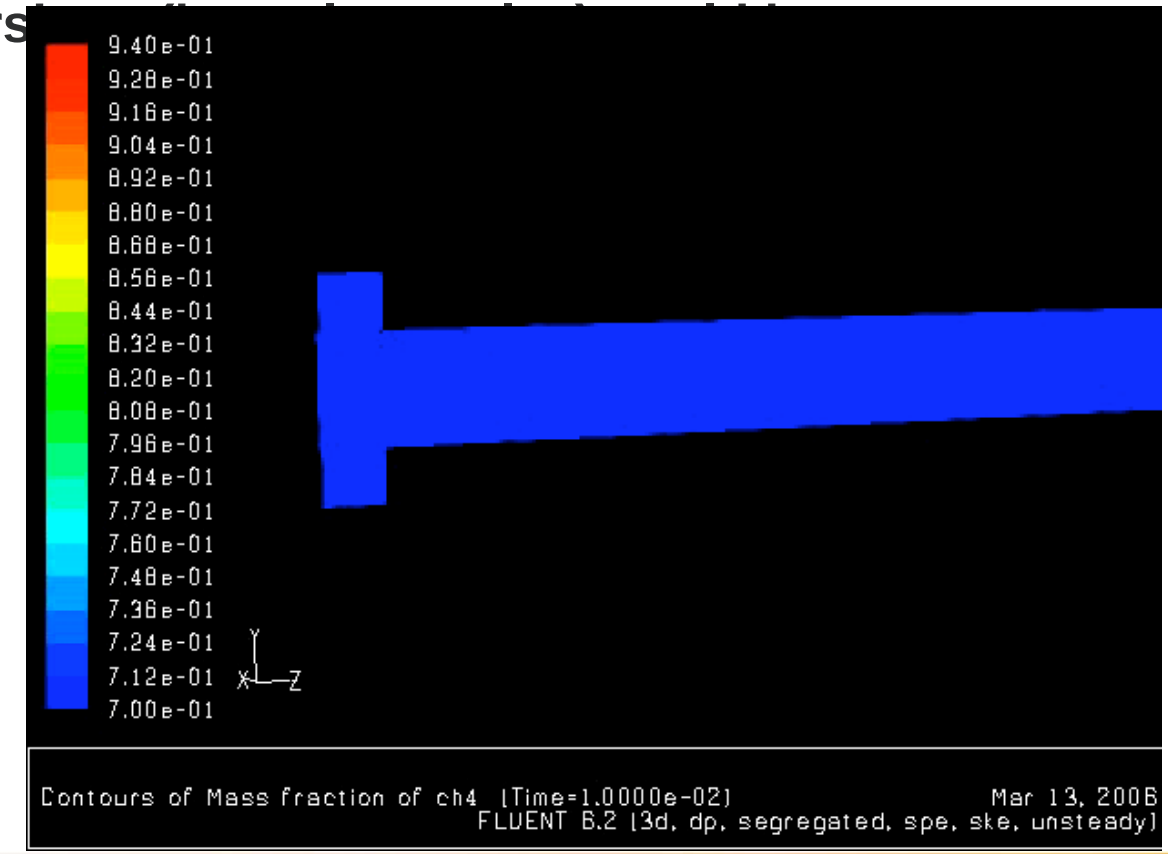
- **Better collection protocols need defined**
  - Data has been collected for a broad range of purposes
  - May not be generally useful (in agreement with NGC+)
- **Re-cip engines – significant body of data**
- **Appliances – several studies**
  - Previous and on-going efforts
- **Turbines – limited data on lean premixed designs**
- **Industrial burners – CEC/GTI effort**
- **Important general issues**
  - How fast can the fuel composition change?
  - Do we have sensors to detect this change?
  - Hydrocarbon "dropout"

Key Findings – CFD Modeling and Pipeline Mixing

- **Steady-state mixing relatively fast (within 100 pipe diameters)**
- **Transient excurs[illegible] significant**

Bulk Velocity	Composition Transient @ 100km
0.5 m/s	224 s
1.3 m/s	54 s
2 m/s	30 s
5 m/s	12 s
10 m/s	10.3 s
20 m/s	10.0 s

Effective Diffusivity = 0.005 m^2/s^2
Switching Time = 1 sec



Key Findings – Pipeline Mixing

- **Steady-state mixing relatively fast (within 100 pipe diameters)**
- **Transient excursions could be more significant**

Bulk Velocity	Composition Transient @ 100km
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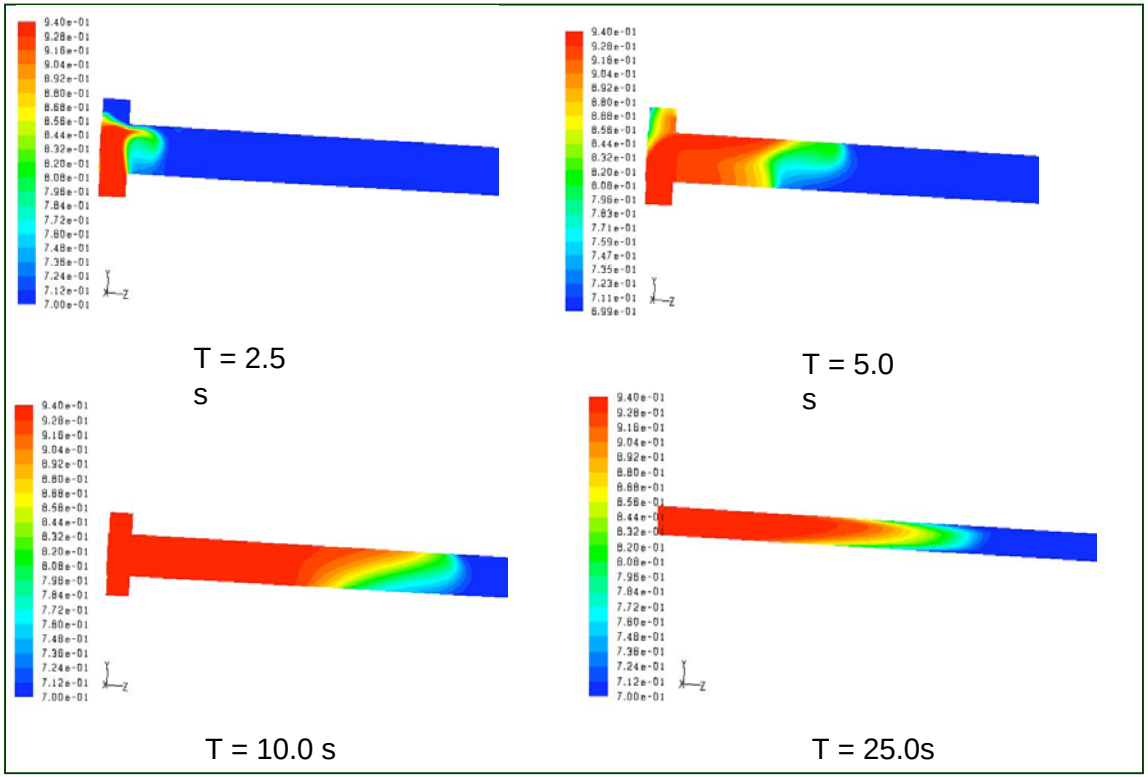


Reciprocating Engines – Key Findings

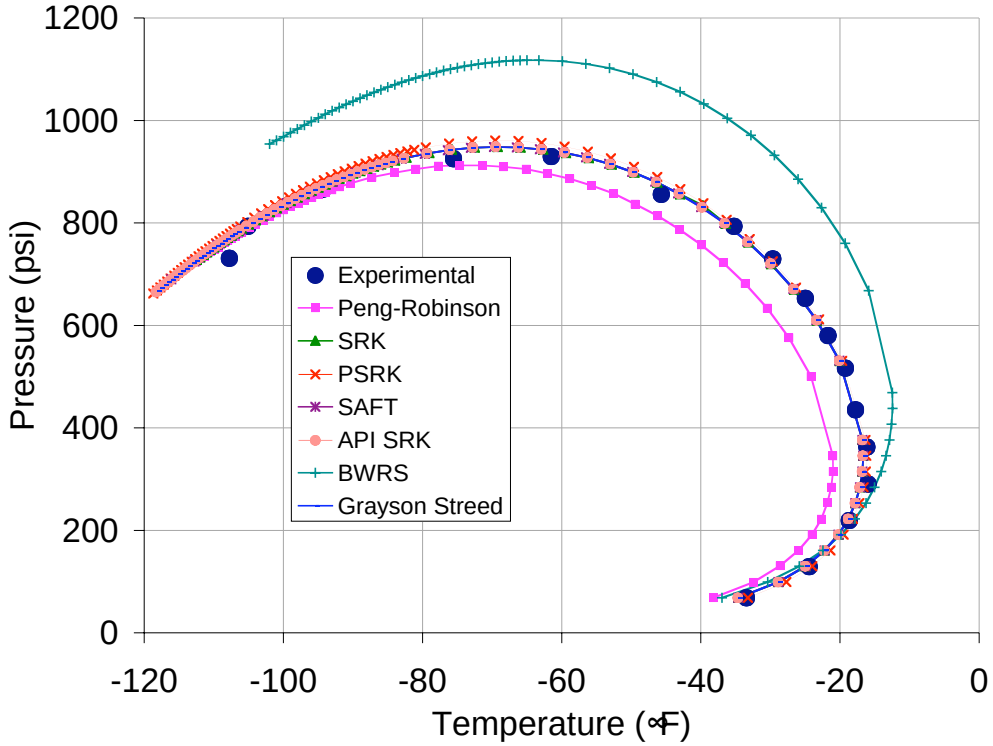
- **Engine control system design will determine impact**
- **Open-loop control systems**
  - Small increases in emissions are possible
  - Legacy engines most affected
- **Closed-loop control systems**
  - No significant impacts expected from LNG-based fuels
    - Timing adjustments may be required (knock sensors)
    - Timing changes may reduce efficiency 1-3%
- **Rapid on-line fuel composition sensors would be useful**
- **Generic engine testing not warranted**

Turbines – Key Findings

- **Engine control system is important**
  - Mass-based fuel metering would be an improvement
- **Lean premixed system (DLN) engines without exhaust after-treatment are most affected**
  - Dynamics
  - Flashback and/or auto-ignition
  - Mixing
  - Emissions
    - No increase observed in NETL tests with 5% pilot
- **Rapid on-line fuel composition sensors would be useful**

HC Dewpoint Assessment – Key Findings

- **16 gas compositions with experimentally determined dewpoints from various sources**
- **Equations of state for vapor-liquid equilibrium**
  - Investigated 7 different models



VLE for Gas Mixture #3 Containing: 96.6% CH4, 0.2% C2H6, 0.1% C3H8, 0.1% C4-C8, 2.8% N2

HC Dew Point – Model Evaluation

$$MAD = \frac{\sum |T_M - T_P|}{n}$$

Name of Model	Mean Absolute Deviation
Peng-Robinson (PR)	2.95
Soave-Redlich-Kwong (SRK)	1.48
Predictive Soave-Redlich-Kwong (PSRK)	1.41
Statistical Associating Fluid Theory (SAFT)	1.43
American Petroleum Institute (API-SRK)	1.48
Benedict-Webb-Ruben-Starling (BWRS)	3.36
Grayson Streed (GS)	1.48

°K

Accuracy of models varies depending on the gas composition (see report for more details)

Gas Turbine Emission Issues

Questions Before Proceeding?

Gas Turbine Issues – Previous Work

- **Public information on LNG performance is limited**
- **Small effect on older diffusion flame systems (+2ppm/100ppm)**
  - Hung, 1976, 1977; Meier, 1998

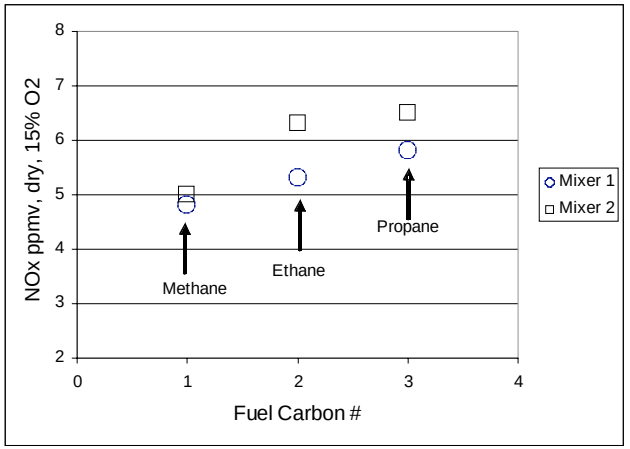
$$\frac{NOx}{NOx_{CH4}} = 1 + 10 \cdot \ln\left(\frac{T}{T_{CH4}}\right)$$

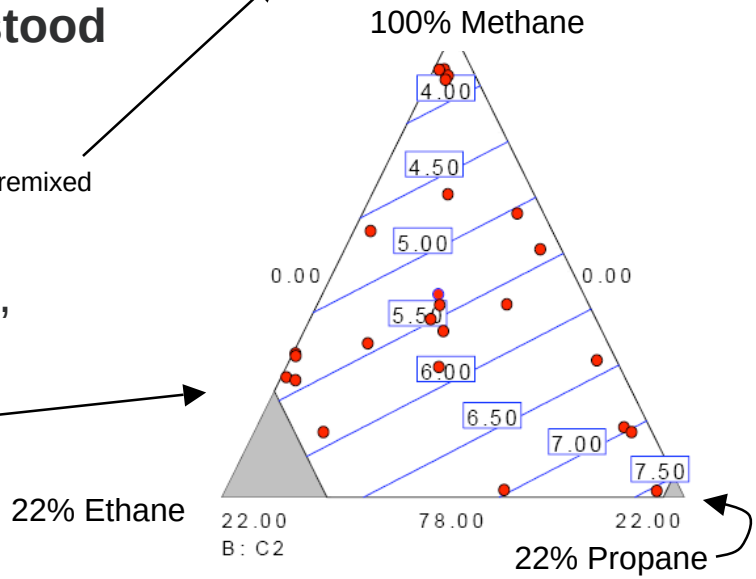
- **Effects on premixed systems not well understood**
  - Lee, 2000

Lee, J. C. Y. (2000). Reduction of NOx Emissions for Lean Prevaporized-Premixed Combustors, PhD Thesis, University of Washington, Seatle WA.

  - Flores, et al, 2001, 2003; Hack and McDonell, 2005

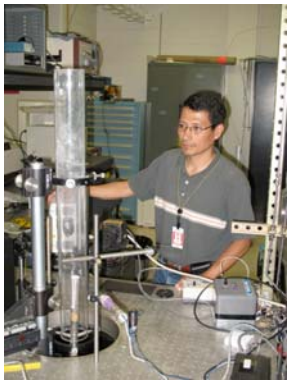
Hack, R. L., McDonell, V. G. (2005). Impact of Ethane, Propane, and Dilunet Content in Natural Gas on the Perfromance of a Commercial Microturbine Generator. ASME GT2005-68777.



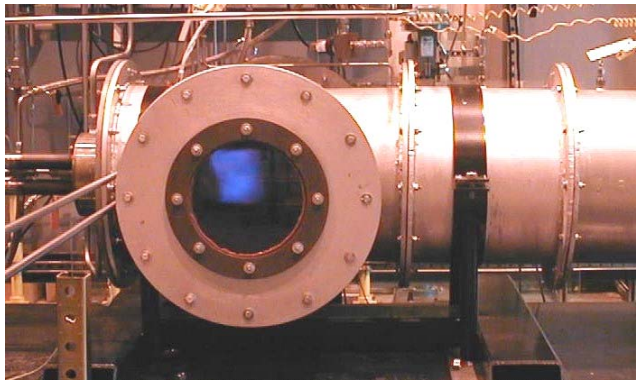


NETL Approach For GT's
(Part Of Larger Effort)

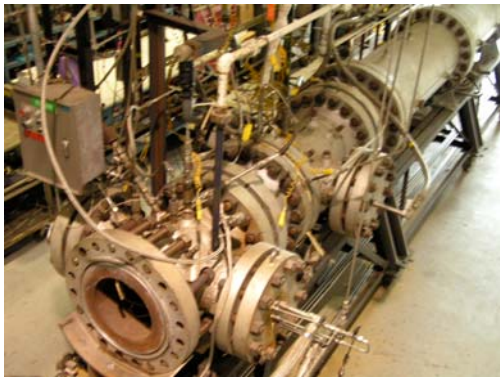
- **Simulated premixed combustion experiments**
  - Lab-scale (Rijke tube burner)
  - Atmospheric swirl-stabilized burner
  - Pressurized DLN nozzle



Lab-scale burner



Atmospheric pressure combustor for screening studies

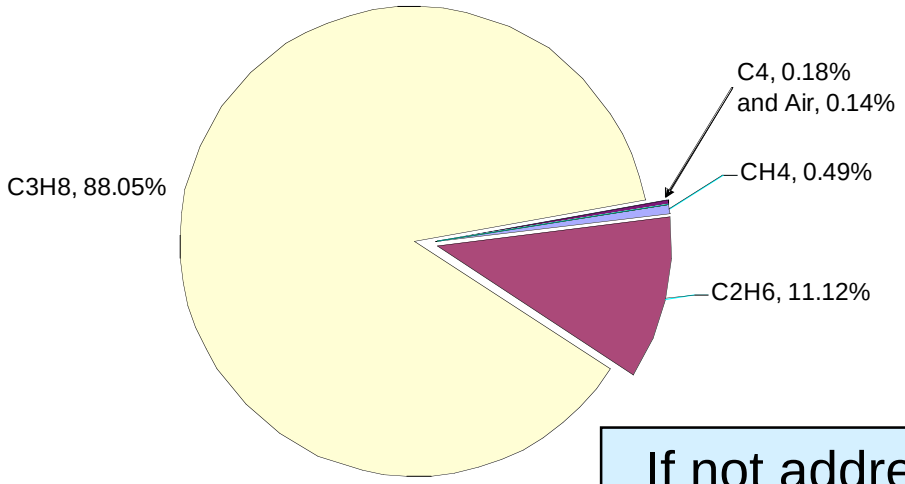


Full-size gas turbine combustor
for changes in stability and emissions

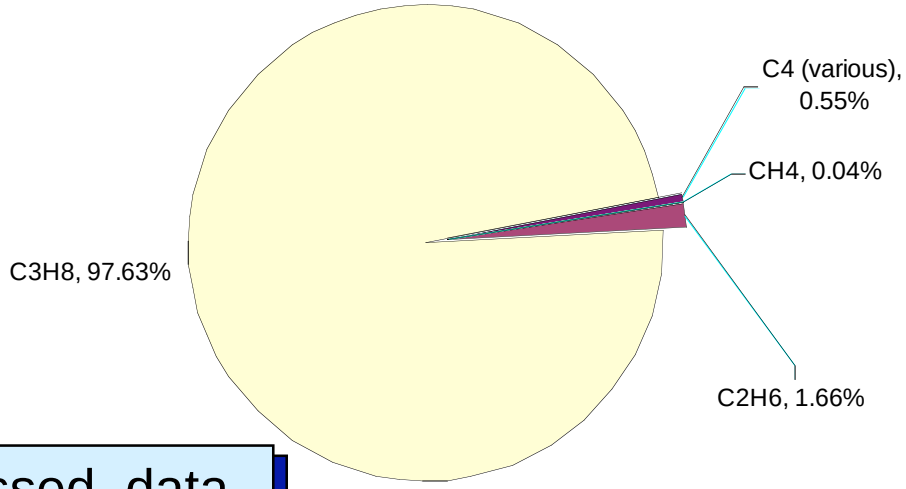
Lessons Learned

- **Propane is not necessarily 100% pure**
  - As-received residential grade propane is nominally 85% propane, 15% ethane (vapor phase)
  - Ethane and methane are more volatile and removed quickly

As-Received

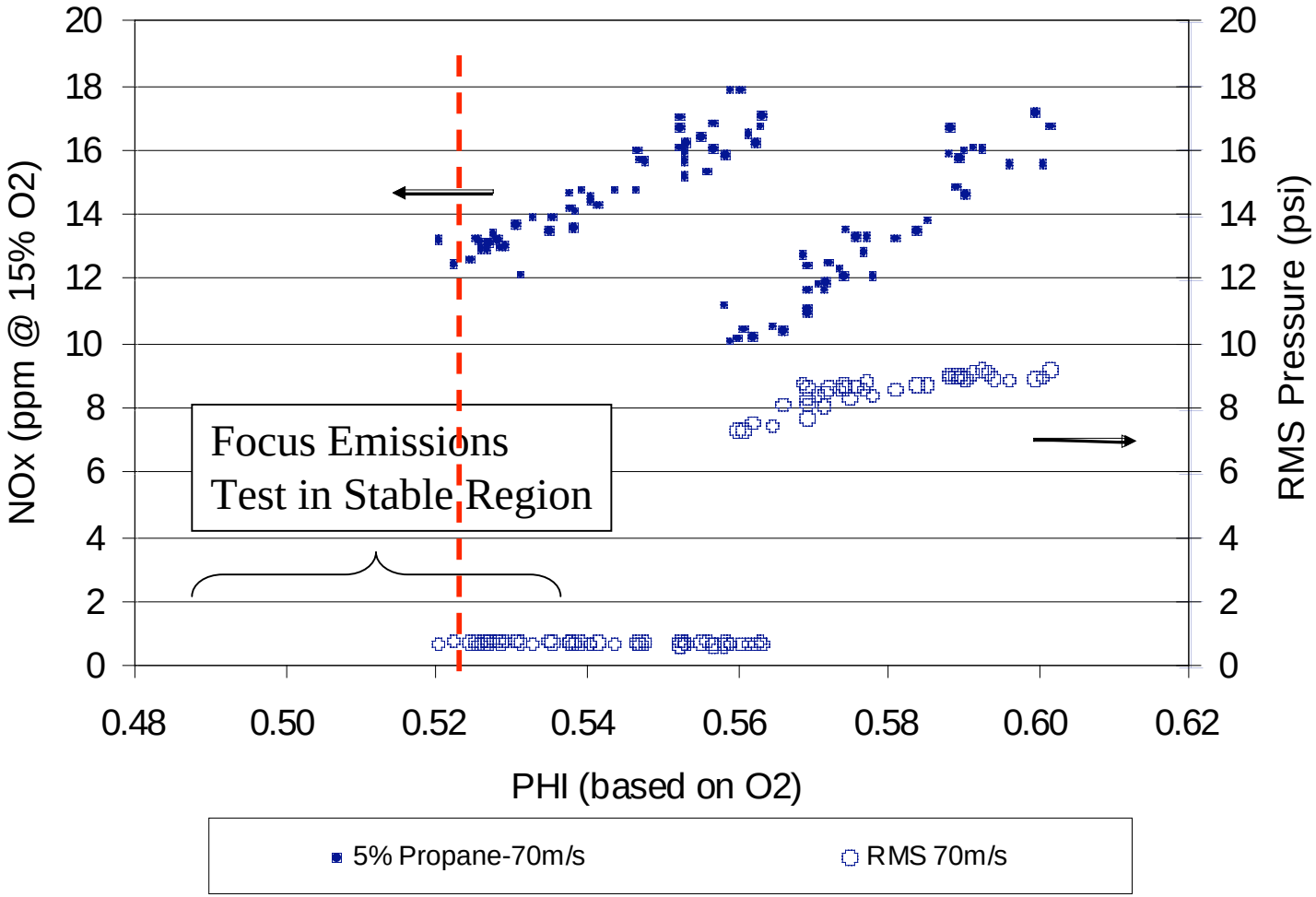


After 2 Hours of Operation

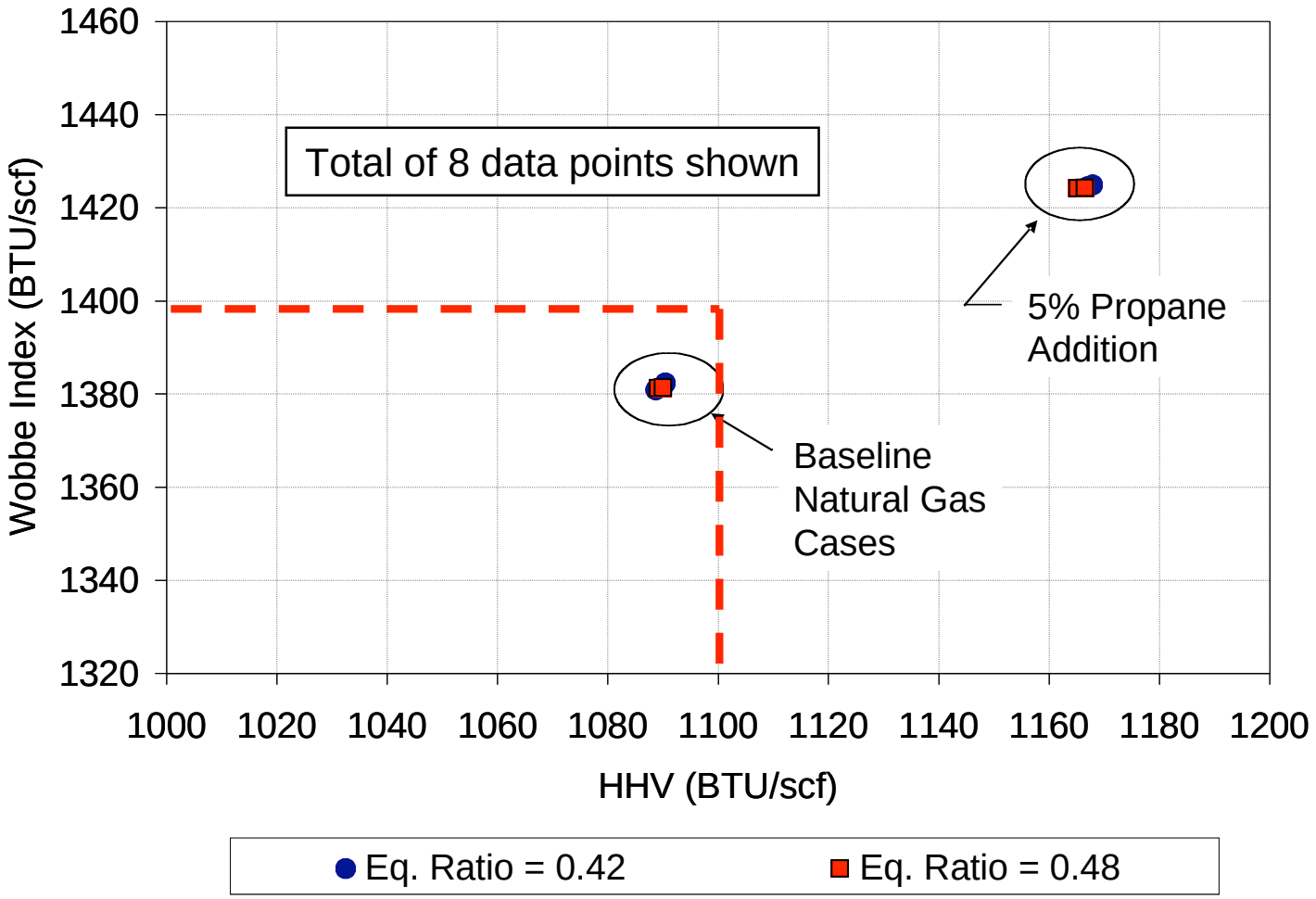


If not addressed, data quality can be impacted

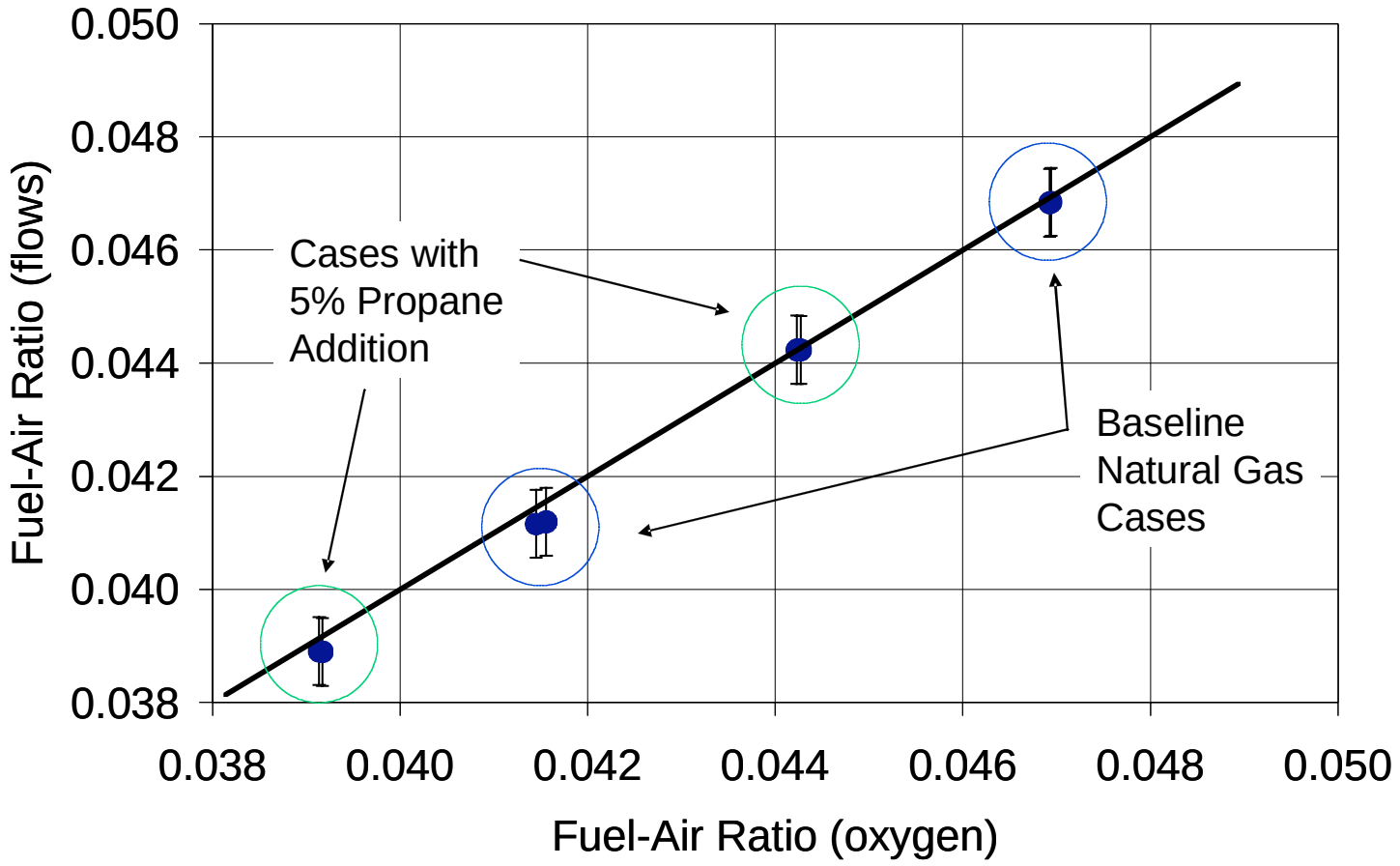
Important Consideration -- RMS Pressure Influences NOx Emissions



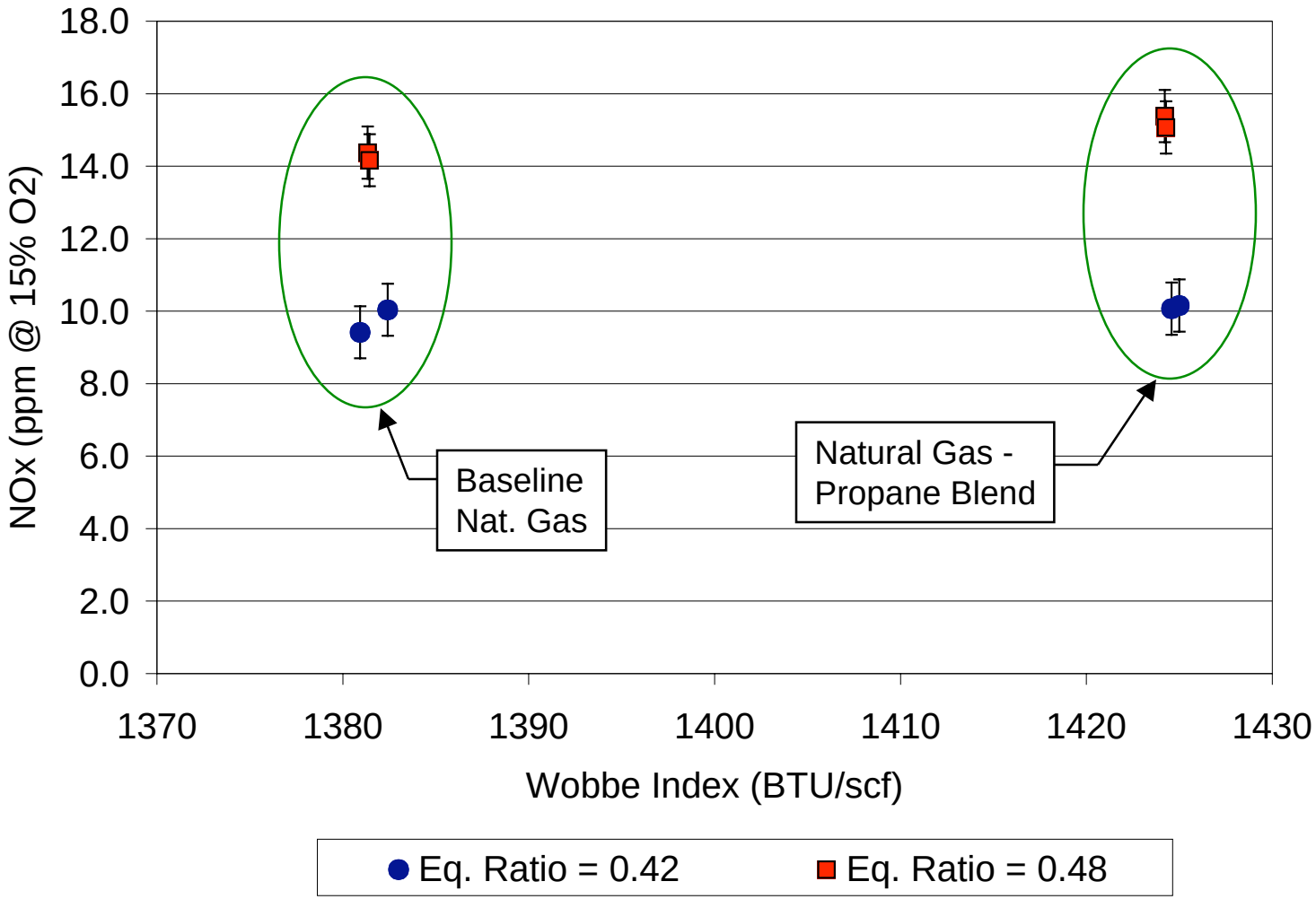
Gas Properties and Blending Repeatibility
(Wobbe: ± 1, HHV: ± 2)



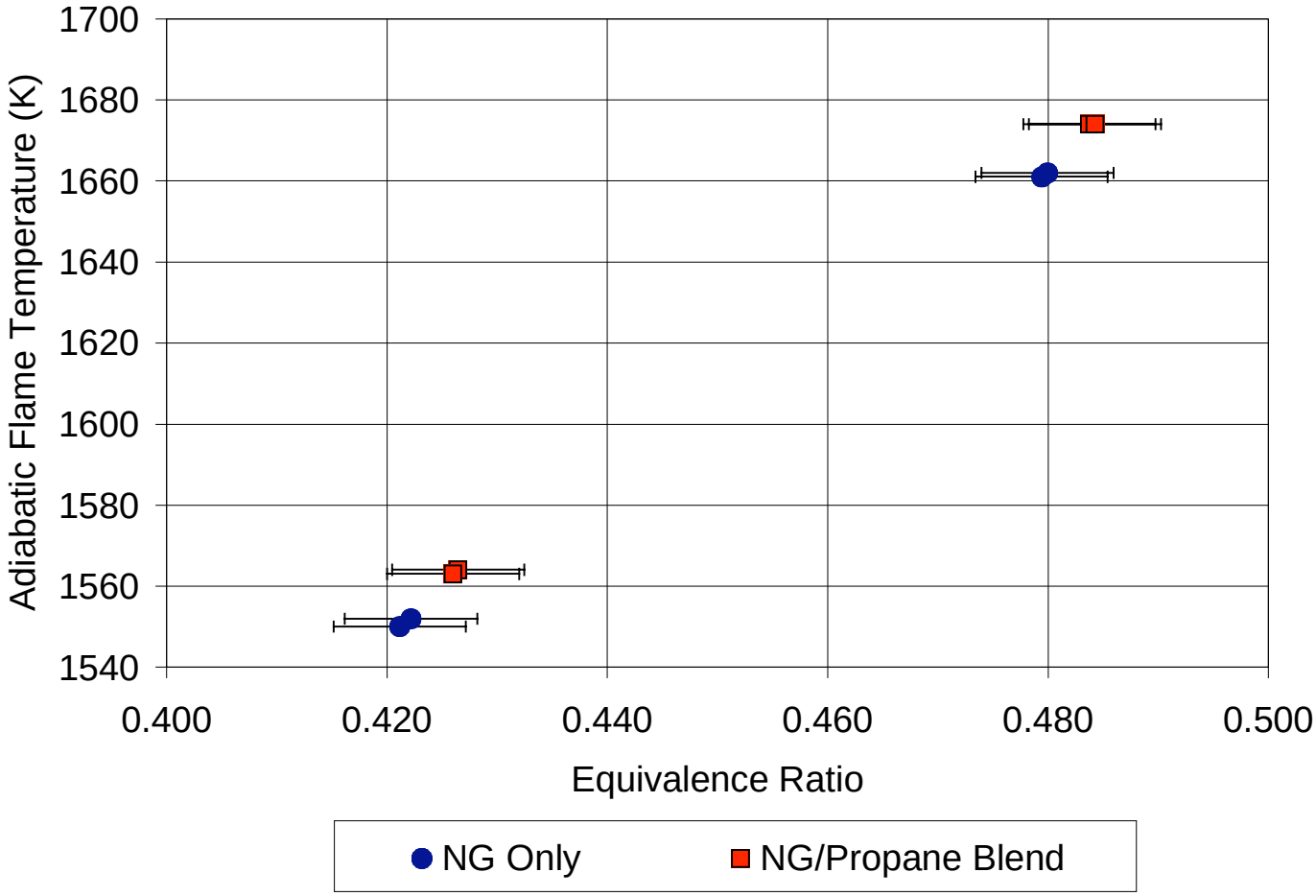
Mass Closure Quality Check



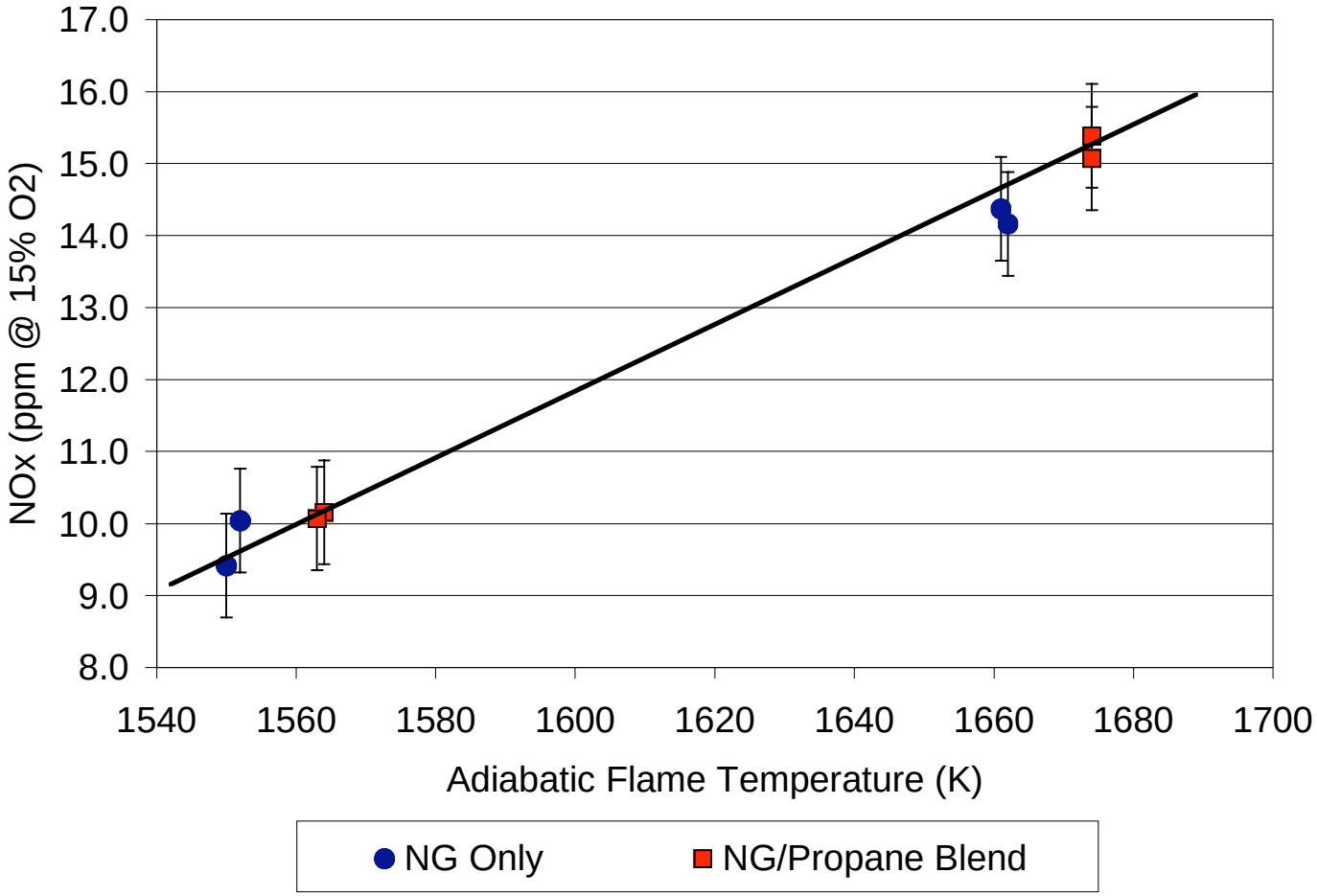
NOx Emissions vs. Wobbe



Variations in Equivalence Ratio and Adiabatic Flame Temperatures



NOx Correlates With Adiabatic Flame Temperature



Summary of Gas Turbine Fuel Interchangeability Issues -- Emissions

- **Wobbe index had no significant effect on emissions**
  - NOx correlates with flame temperature
  - Flame temperature is weak function of C:H ratio (see Gulder)
- **Lean premixed systems without exhaust after-treatment are most at-risk**
- **NETL results show no significant emissions impact over a realistic range of fuel compositions**
  - Differs from previous work (UC-Irvine and U. of Wash.)
  - Differences
    - NETL tests were not 100% premixed
      - 5% of fuel was diffusion pilot
      - Thermo-acoustic instability constraints
    - NETL results covered more “realistic” range of compositions

Questions or Comments . . .

Final report publicly available @

– http://www.ferc.gov/industries/lng/indus-act/issues/gas-qual.asp